A study on the wind-induced vibration response material characteristics of typical and atypical high-rise buildings according to changes in corner shapes material

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Abstract. High-rise buildings have very slender, atypical, and lightweight shapes such that the higher they become, the more flexible they are, and it is very important to review closely the structure behavior, stability, and usability when designing ultrahigh-rise buildings with a great influence from dynamic load. Accordingly, the wind-induced vibration characteristics according to shapes and edge shape changes were experimented. The wind load spectrum, basic type showed the greatest peak value, but the corner cut reduced the magnitude of the peak. The maximum displacement response was slightly reduced in the across-wind direction and greatly reduced in the along-wind direction for A-type. For B-type, the across-wind direction showed a distribution similar to that of the corner cut model, and the along-wind direction saw similar reductions in the basic model and corner cut. The maximum displacement response value was found to be B>A(type) for across-wind direction and A >B(type) for along-wind direction.

Introduction

In the case of high-rise buildings, shapes are slender and atypical and flexibility increases as the number of floors increases, because the buildings have been lightened. As the damping ratios of high-rise buildings are small, any wind or seismic load may act quite adversely. When designing super high-rise buildings that are greatly affected by dynamic loads, the behavior, stability, and usability should be carefully reviewed [1-5]. With respect to reducing the vibration responses of high-rise buildings to wind loads, methods of changing the exterior shapes of high-rise buildings [6] and methods of controlling vibrations by attaching vibration control devices have been studied. Many studies have been conducted on methods of changing the entire exterior of high-rise buildings and methods of reducing the occurrence of vibrations of high-rise buildings by changing some corner shapes (Fins, Vented Fins, Slotted Corners, Chamfered Corners, Corner Cutting) [7]. However, there are difficulties in reducing the vibrations of high-rise buildings, even with such methods, and methods of controlling vibrations by attaching a vibration control device to the top of the top floor and other methods are used. This study examines the characteristics of wind-induced vibrations of Y-type planes that are frequently used in apartment structures currently as a method of changing the exterior shapes and corner shapes of high-rise buildings, and the changes in the characteristics of wind-induced vibrations following changes in corner shapes.

Experimental Model

The size of the measurement area of the boundary layer wind tunnel used in the wind tunnel experiment was 2.1 (width) × 1.7 (height) × 18 (length). In the present experiment, a model scale of

1/400 was used. Fig. 1 shows the sizes, axis definitions, and wind angles of the models used in the wind tunnel experiment. In total, six models were used in the wind tunnel experiment. A square model (A-1) and a Y-shaped atypical (B-1) model were used as the basic models. In addition, four additional models were produced by installing corner cuts and chamfers at the corners of these models. Fig. 2 shows the shapes of the actual experimental models. The cross-sectional area of the models was made to be 100 cm and the height of the models was made to be 40 cm identically. The models were made using balsam wood so that the models would be lightweight to ensure that the natural frequency of the models for the wind power experiment would be at least 50 Hz. The air current condition for the wind tunnel experiment was set to suburban districts (α= 0.15). The basic wind velocity at the building to be analyzed was assumed to be 30 m/s. In total, 36 wind angles at intervals of 10° were used in the experiment. For data analysis, a sampling frequency of 200 Hz was used, and an average of five tests was taken. Table 1 shows the dynamic characteristics of the high-rise buildings necessary for the analysis of the results of the wind tunnel experiment. Table 2 shows the similarity law of the wind tunnel experiment.

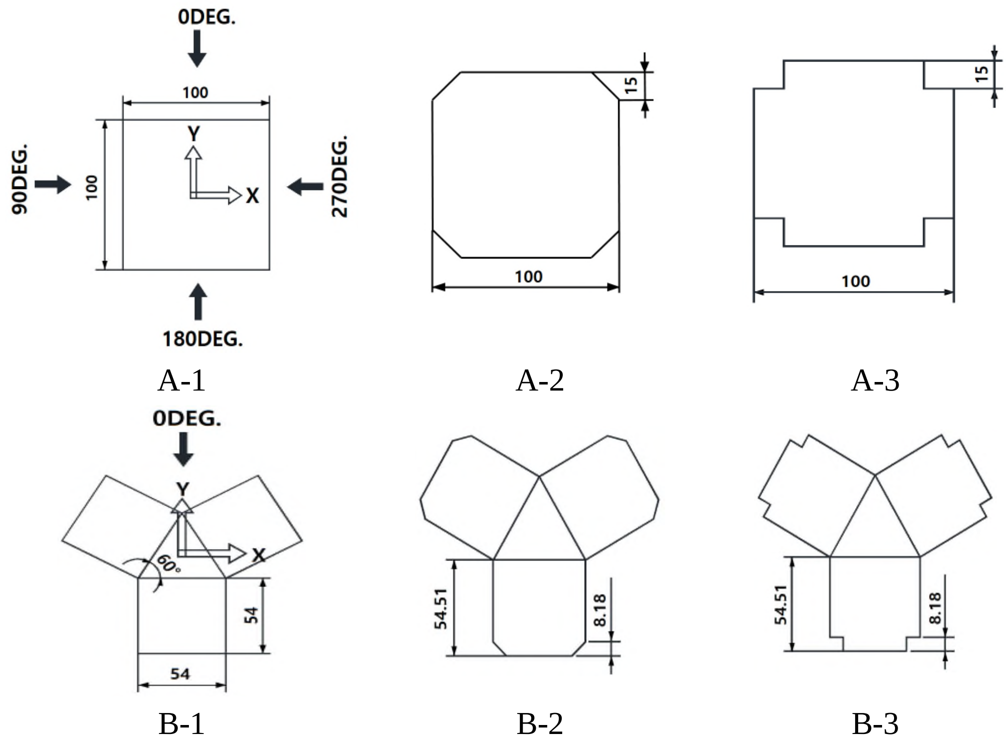


Fig. 1 The shapes, sizes, and wind angles of the experimental models.

Fig. 2 Actual experimental model.

Table 1. Dynamic characteristics of the analysis building.

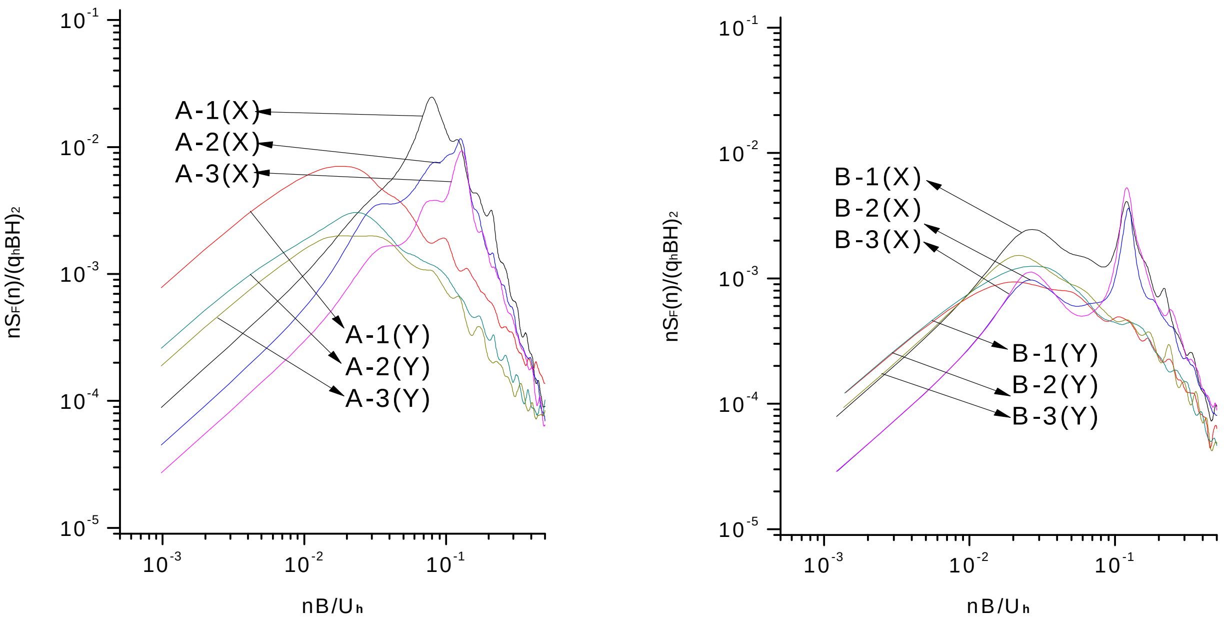
cross-section area (B × D)		$1600m^2$
Height (H)		160 m
Natural Frequency (Hz)	nFx	0.2
	nFy	0.2
	nFz	0.35
Building bulk density (kg/m^3)		250
Total mass (kN)		64000
Damping ratio		0.02

Table 2. The similarity law of the wind tunnel experiment.

Roughness division	suburban districts (α=0.15)	Roughness division	suburban districts (α=0.15)
Model scale	1/400	Sampling Frequency	200Hz (0.005sec)
Design wind velocity (m/s)	45.6	Measurment time (sec)	20.48
Wind tunnel velocity (m/s)	5	Actual time(min)	15
Velocity scale	9.12	Ensemble average	5 time (4096 data)
Time scale	43.9	Lowpass Filter	100Hz

Wind Load Spectrum Analysis

Fig. 3 shows the wind load spectra that act across (X-axis) and along the wind (Y-axis). The area of discussion of the wind load spectra is limited to the high-reduced frequency range of at least 0.1, because it is included in the wind velocity range used in the designs of most high-rise buildings. In the case of A-type, which is the basic model, the peaks appeared when the wind angle was 0°, and the peaks of the along wind direction (Y-axis) appeared when the reduced frequency was 0.1 or lower. In addition, the sizes of the spectra were shown to be smaller when there were corner cuts than when there were no corner cuts in the basic model. The methods of corner cuts did not affect the along wind spectrum. In the case of B-type, which is the atypical model, the peaks of the along wind spectrum appeared when the reduced frequency was 0.1 or lower, as did with A-type. Corner cuts were shown to have no effect on the along wind spectrum. Across wind (X-axis) peaks at the wind angle of 0° appeared around the reduced frequency of 0.1. The peak sizes of the across wind spectra were shown to be the largest in the basic model, decreasing in size with methods such as corner cuts. The shapes of corner cuts, however, were shown to have no effect on the across wind spectrum.



a) A-type b) B-type

Fig. 3 Wind load spectrum (α = 0.15) at a wind angle of 0°.

Maximum Displacement Response

Fig. 4-5 show the across wind (X-axis) and along wind (Y-axis) maximum displacement responses for 36 wind angles. The maximum displacement responses can be expressed in the equation

$$X_{\max} = \overline{X} + g \cdot \sigma \tag{1}$$

There, σ = rms displacement

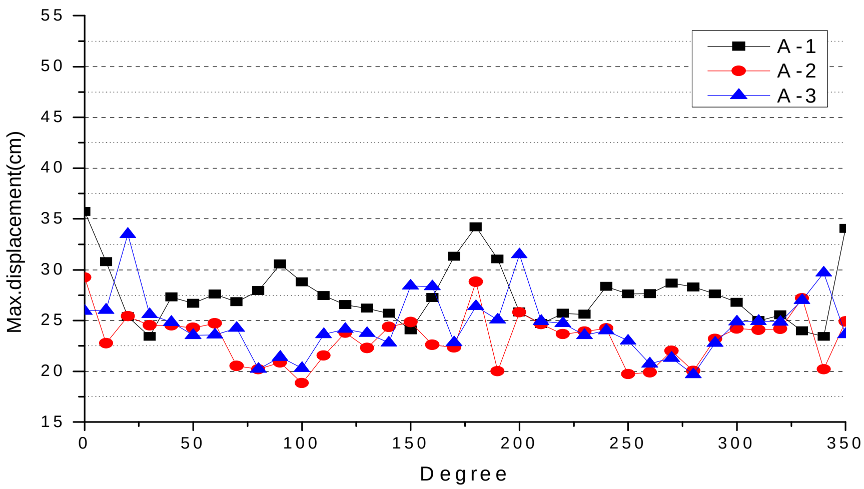
$$\sigma = (A_B + A_R)^{1/2}$$

$$= \left[\frac{\sigma^2{}_M}{\left\{ (2\pi n_0)^2 M_1 \right\}^2} + \frac{\pi n_0 \cdot S_M(n_0)}{4\eta_1 \cdot \left\{ (2\pi n_0)^2 M_1 \right\}^2 \cdot H^2} \right]^{1/2}$$

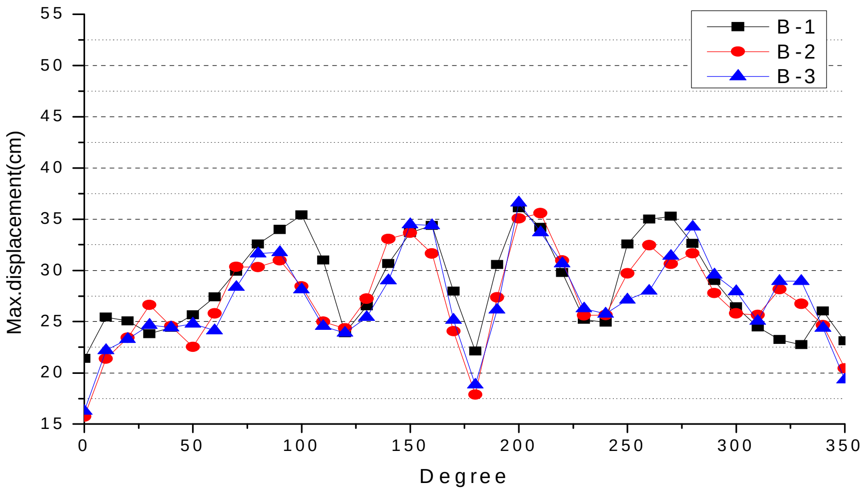
$$= \frac{\sigma_M}{(2\pi n_0)^2 M_1 \cdot H} \left(1 + \frac{\pi}{4\eta_1} \cdot \frac{n_0 S_M(n_0)}{\sigma^2{}_M} \right)^{1/2}$$

There, σ_M : Standard deviation of overturing moment

In the case of the basic A-type, across wind (X-axis) maximum displacement responses were shown to be smaller in models with corner cuts at all wind angles except for 30°, 150°, 210°, and 330°. The maximum displacement responses did not differ according to corner cut shapes. The differences in displacement responses, however, appeared at certain angles. The displacement responses decreased in A-2 by up to 30% compared to the basic model. In the case of B-type, the atypically shape, the maximum displacement responses were distributed similarly as in the models with corner cuts at most wind angles except for around certain angles, including 90° and 270°. The sizes of across wind (X-axis) maximum displacement responses were shown to be larger in B-type than in A-type. In the case of A-type, the along wind (Y-axis) maximum displacement response values decreased drastically in the models with corner cuts. In the case of B-type, however, the along wind (Y-axis) maximum displacement response values decreased similarly in both the basic model and the models with corner cuts. The sizes of along wind (X-axis) displacement responses were shown to be larger in A-type than B-type.

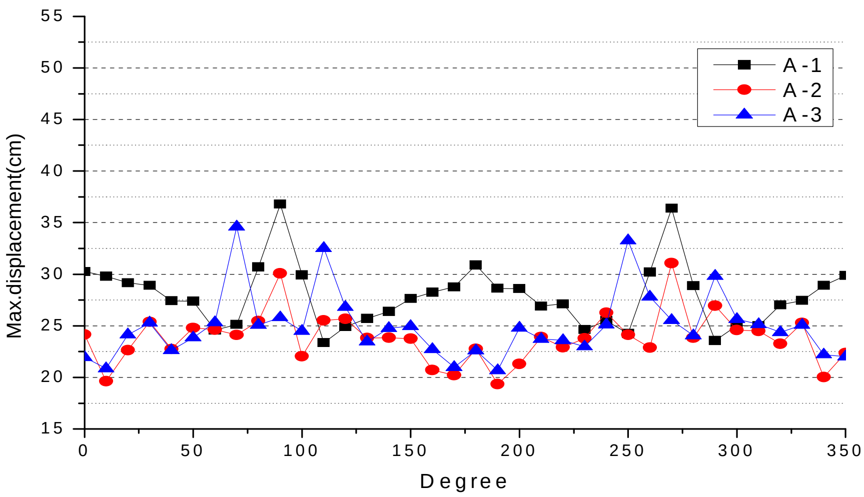


a) A-type

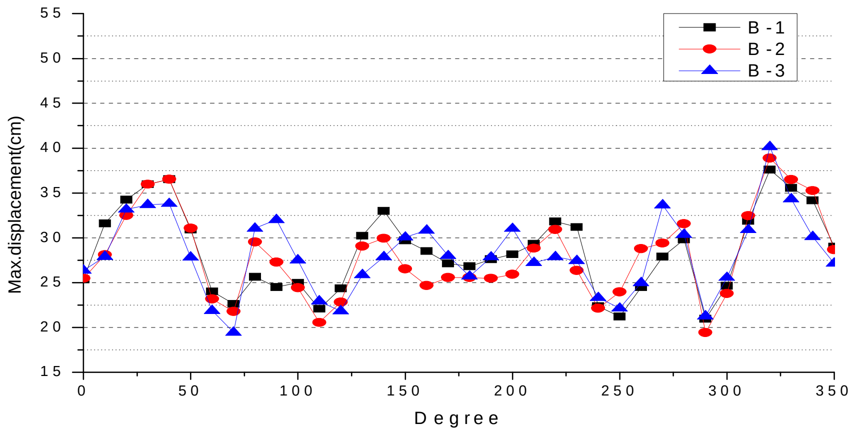


b) B-type

Fig. 4 Maximum displacement responses (across wind) in suburban districts (α= 0.15) by wind direction.



a) A-type



b) B-type

Fig. 5 Maximum displacement responses (along wind) in suburban districts (α= 0.15) by wind direction.

Conclusion

The characteristics of wind-induced vibrations of typical and atypical high-rise buildings were analyzed and the following conclusions were drawn. A typical building (A-type) showed a larger wind load spectrum than the atypical one (B-type) did. In case the corner of the high-rise building is cut, however, the typical type showed a larger decrease in wind load spectrum than the atypical type did. We could confirm that the corner change hads large effects on reducing wind load. Moreover, a typical high-rise building with cut corners showed larger effects on vibration reduction than an atpicayl high-rise building did. In some of the wind direction angles, the maximum vibration displacement of a typical high-rise building with cut corners decreased at most 30%. In case of an atypical high-rise building, the maximum effects of corner cut were less than 100% of that of a typical high-rise building.

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References

[1] M. J. Hocraniner, C. Adam, F. Ziegler, Application for tuned liquid column dampers for passive structural control, CD-ROM paper 7th ICSV (2000) 4-7.

[2] K. Yalla, Liquid dampers for mitigaton of structural response theoretical development and experimental validation, Ph. K., University of Notre Dame (2001).

[3] J. C. Wu, Y. P. Wang, C. H. Lee, P. H. Liao, Y. H. Chen, Wind-induced interaction of a non-uniform tuned liquid column damper and a structure in pitching motion, Eng. Struct. 30 (1998) 3555-3565.

[4] A. Kareem, T. Kijewski, Mitigation of Motions of Tall Buildings with Specific Examples of Recent Applications, Wind. Struct. Int. J. 2(3) (1999) 201-251.

[5] S. K. Yalla, A. Kareem, Optimum absorber parameters for tuned liquid column dampers, ASCE J. Struct. Eng. 126 (2000) 906-915.

[6] T. Balendra, C. M. Wang, G. Rakesh, Effectiveness of TLCD on various structural systems, Eng. Struct. 21 (1999) 291-305.

[7] C. C. Chang, C. T. Hsu, S. S. Swei, Control of buildings using single and multiple tuned liquid column dampers, Struct. Eng. Mech. 6 (1999) 77-94.